COMPARISON OF BACK-CALCULATED SASW PROFILES WITH RESULTS FROM CORING AND DCP TESTING

V.Khanna[1] and M.A. Mooney[2]
[1]Graduate student, School of Civil Engineering and Environmental Science, University of Oklahoma, Norman, OK 73019, vkhanna@ou,edu. [2]Associate Professor, School of Civil Engineering and Environmental Science, University of Oklahoma, Norman, OK 73019, mooney@ou.edu.

Abstract

As part of a study into the state of pavements at Oklahoma's general aviation (GA) airports the Spectral Analysis of Surface Waves (SASW) method was employed. The main objective of using the SASW method was to provide a reliable, quick, non-destructive determination of pavement layer thicknesses and moduli at 71 GA airports. This enabled the determination of pavement structural capacity and an estimation of remaining life. SASW data were processed using WINSASW software developed by the University of Texas at Austin. Boring logs and sample recovery using coring equipment and a hand auger were also performed at all test sites. Dynamic cone penetrometer (DCP) tests were conducted to a depth of 4 ft in each borehole after core removal. The classification of SASW-estimated modulus profiles into pavement layers was more accurate when pavement section details (e.g., boring logs) were available for guidance. SASW-estimated base thickness differed from actual base course thickness by 10 – 30%. SASW estimated the layer moduli of underlying soils more accurately for AC pavements than for PCC pavements. SASW-predicted moduli of subgrade soils under PCC pavements were overestimated. SASW was able to differentiate between adjacent soil layers only when there was a significant contrast in dynamic penetration index, and thus modulus.

1.0 Introduction

Over the years federal and state transportation agencies have invested vast sums of money in highway and airport pavements, resulting in the creation of the present day trillion-dollar network. In order to maximize the utilization of this asset, it is necessary that the system be maintained at an optimal level of serviceability. Owing to the above, both federal and state transportation agencies are paying greater attention to asset management of highway and airport pavements. The underlying objective of this effort is to achieve the most efficient deployment of resources in maintaining a pavement network at its fullest capacity.

In line with the above goal, the Oklahoma Aeronautics and Space Commission (OASC) is developing an airport pavement management system for 71 GA airfields in the state. Oklahoma's network of GA airfields consists of both PCC and AC pavements that range in age from 1 to 60 years. Many of these pavements require maintenance, repair or rehabilitation yet the most appropriate maintenance and rehabilitation (M&R) strategies must be selected only after the exact nature and cause of the pavement distress has been ascertained.

The spectral analysis of surface waves (SASW) method was adopted to provide in-situ determination of pavement layer thicknesses and their moduli. As a result of the estimation of these mechanistic parameters, the structural capacity and remaining life of the pavements can be computed. Additionally the type of M&R most suited for the exhibited pavement distress could be selected for each airfield pavement. This paper compares results of testing at five GA airport pavements using coring with hand augering, DCP testing and the SASW method.

2.0 Efficacy of SASW Method

Since developing the SASW technique in the 1980's (Nazarian and Stokoe 1985, 1986), numerous studies have been performed to assess its ability and accuracy. Nazarian *et al.* (1988) used the SASW and the falling weight deflectometer (FWD) methods at nine sections of the pavement test facility of the Texas A&M University. Coring was not performed. The backcalculated layer thicknesses differed by 4 - 20% with construction drawings of the test sites. SASW moduli were within 30% of the moduli determined using the FWD. Roesset *et al.* (1990) concluded from their tests that moduli measured at strain levels associated with seismic testing are maximum values and that the high frequencies used in the SASW test result in higher modulus values for AC material. The thickness of the surface layer matched almost exactly with cores from the site. The authors also present data on the reduction of surface layer moduli with temperature.

Rix *et al*. (1990) reported that surface layer modulus for PCC determined by SASW was within 10% of the in-situ value and that of other near-surface layers to about 10 – 30% of in-situ values. The in-situ modulus was estimated by multiplying SASW modulus with the normalized modulus obtained from laboratory testing. Hunaidi (1991) reported results that over-predicted the thickness of old AC pavement layers by 40%. AC overlay thickness could not be accurately determined. He attributed this to limitations imposed by available transducers. Nazarian *et al*. (1995) reported a deviation of 20% in the back-calculation of PCC thickness using the SASW method. Nazarian *et al*. (1999) reported that for AC layers, moduli measured in-situ and in the laboratory with different seismic testing devices are very close. For the base and the subgrade, there is good agreement between seismic moduli measured in the field and in the laboratory as long as density and moisture contents of the materials are similar. Nazarian *et al*. conclude that moduli measured with seismic methods are higher than those obtained from other testing methods such as the resilient modulus and FWD testing. Addo (2000) concluded that AC thickness could be estimated with SASW testing to an accuracy of about 6% if the AC is in a good condition.

3.0 Experimental Program

SASW and DCP test results as well as boring logs are presented herein for runway locations at five Oklahoma GA airports: Chickasha, Duncan, Ada, Antlers and Chandler Municipal. The runways at Chickasha and Duncan airports are PCC pavement while those at Ada, Antlers and Chandler are AC pavement. The pavement history and surface course profiles as determined by coring are summarized in Table 1 and 2. The Ada profile consists of two layers of AC – an initial 2.5 inch layer (1942) overlaid by 4.5 inches of AC (1964). A 13.0 inch layer of sandy gravel forms the base course resting over 11.0 inches of a fine sandy subbase and a silty clay subgrade. Two layers of AC were observed at Antler’s airport – the original 6.0 inch layer (1973) overlaid with 1.0 inch of asphalt (1990). The profile consists of a 6.5 inch

Table 1: AC surface course details

Airport	Layer	Age (Yrs)	AC Thickness from coring (in.)		Pave. Temp during Testing (^{o}F)	Section PCI
			Layers	Total		
Ada	Overlay	37	4.5	7.0	99	50
	AC layer	59	2.5			
Antlers	Overlay	11	1.0	7.0	83	33
	AC layer	28	6.0			
Chandler	Overlay	9	3.5	5.0	110	59
	AC layer	18	1.5			

silty clay base course resting atop a clayey silt subgrade. The Chandler profile consists of a 1.5 inch thick AC layer (1983) and 3.5 inches of AC (1992) overlaying an 11.0 inch base of clayey sand and a 17.0 inch clayey subbase. The structure is supported on a clayey subgrade.

Table 2: PCC pavement details

Airport	Layer	Age (Yrs)	PCC Thickness	Pavement Temp during Testing	Section PCI
Chickasha	AC layer	22	7.0	80	91
Duncan	AC layer	37	7.5	79	81

The Chickasha profile consists of a 7.0 inch PCC slab with a 4.0 inch base of gravelly sand over a low plasticity clayey subgrade. The Duncan profile is comprised of a 7.5 inch PCC slab with an 8.5 inch silty clay base and a 15.0 inch subbase. The structure is supported by a hard clay subgrade. The pavement condition index (PCI), computed based upon visual surveys, was used to better describe pavement health at the time of testing (shown in Table 1). The PCI rating system (evolved by the U.S. Army Corps of Engineers) is a numerical index that ranges from 0 for a failed pavement to 100 for a pavement in perfect condition.

3.1 Overview of the SASW method

The SASW method is based on the dispersive character of surface waves propagating in a layered medium. Figure 1 illustrates the most commonly used field configuration for the test. The test employs common receivers midpoint geometry (CMRP, i.e. $d_1 = d_2$ in Fig. 1) and receiver spacings of 0.5, 1, 2, 4, 8 and 16 feet. Surface waves are generated in the material being tested using the impact from a hammer source. The time series of recorded signals is recorded by receivers R_1 & R_2 and is Fourier transformed to the frequency domain. In the frequency domain, the transfer function and the coherence function for the recorded signals is computed. From the phase information of the transfer function and the coherence function for the different receiver spacings, a shear wave versus wavelength profile for the test site is generated. This is commonly referred to as the experimental dispersion curve. The dispersion curve is inverted to obtain the elastic modulus versus depth. The inverted profile is used to compute the forward model, which should approximate the experimental dispersion curve. The forward model is commonly referred to as the theoretical dispersion curved. Inversion and forward modeling is an iterative procedure whereby the forward model is refined and improved. This yields a forward model that is representative of the section being tested.

There are several softwares available for inversion. In this study, WINSASW developed at the University of Texas at Austin software based upon the Haskell-Thomson matrix algorithm (Thomson 1950 & Haskell 1953) has been used. SASW data was collected using a portable computer manufactured by Olson Engineering (Wheat Ridge, Colorado). The computer uses a data acquisition card manufactured by National Instruments and appropriate signal conditioning systems. The sensors used included uniaxial accelerometers manufactured by PCB Piezotronics, and 4.5Hz geophones manufactured by Geo Space Corporation. TFS version 1.76 software was used for data acquisition and processing to obtain the transfer function. WINSASW software was used to construct the experimental dispersion curves and to perform the forward modeling.

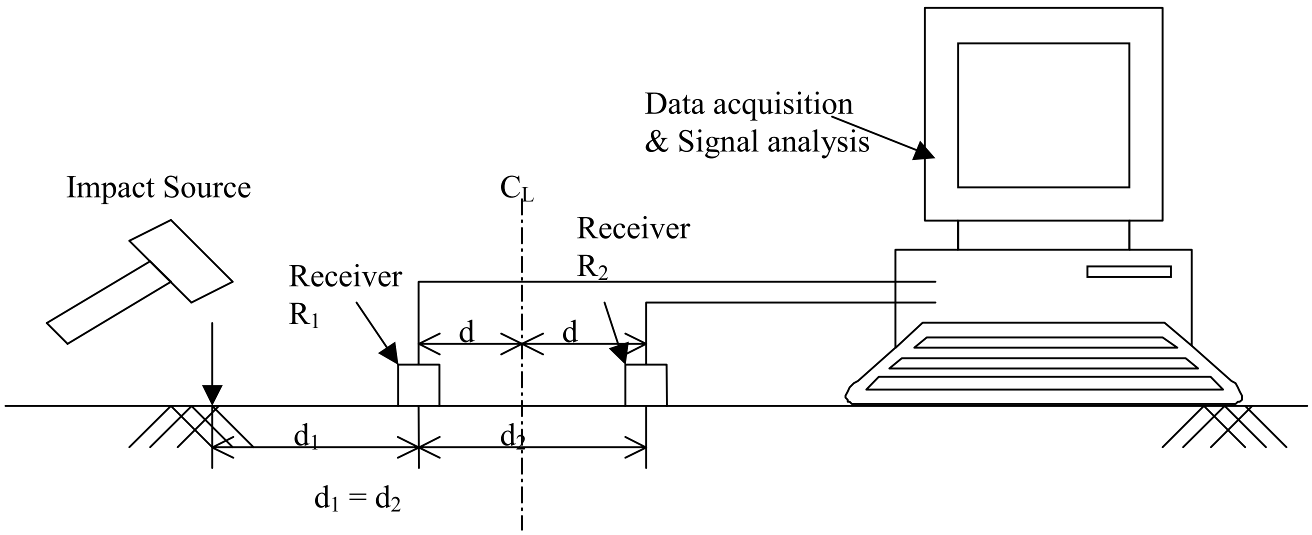

Figure 1: field setup for SASW testing

3.2 DCP testing

The DCP is a hand held soil-testing device consisting of two slender rods, one with a conical tip at one end and an anvil at the other end. The second rod has threads at one end to enable coupling with the anvil and a handle at the other end by which the operator holds the device. A dropped collar weight makes contact with the anvil to push the conical tip into the ground. The test yields a dynamic penetration index (DPI) profile, wherein DPI is measured in penetration distance per hammer blow. DPI values obtained from DCP testing have been correlated to the California Bearing ratio (CBR) and resilient modulus (Ayers *et al.* 1999).

4.0 Results

4.1 Flexible pavement surface course

Results of SASW testing and analysis at Ada are presented in Figure 2 along with results of DCP testing and visual classification of pavement core and extracted soil samples. SASW data reveals five constant modulus layers with moduli decreasing from 2200 ksi at the surface to approximately 400 ksi at a depth of 10.5 inches. On average, the modulus of the AC overlay is much greater than that of the original AC layer. Further, the modulus reduction observed within the AC overlay suggests material deterioration in the lower half. Without the benefit of a boring log, it is reasonable to assume a SASW-predicted surface course thickness of 10.5 inches. Hence, SASW over predicts the actual total AC

thickness of 7.0 inches by 50%. A review of the SASW backcalculated data in conjunction with the boring log reveals that the 600 ksi modulus observed from a depth of 7-10.5 inches is a numerical error.

SASW data recorded at Antlers indicates the existence of four constant modulus layers with moduli decreasing from 700 ksi at the surface to approximately 55 ksi at a depth of 10 inches (see Fig. 3). While the SASW profile does not reveal a change in modulus from the 1 inch overlay to the 6 inch AC layer, the profile does reveal degradation at the bottom of the original AC layer. This is consistent with the fact that the original AC layer crumbled upon coring. Without the guidance of boring log data, one might conclude that SASW results over-predict the total actual AC thickness of 7 inches by about 40%, presuming that the modulus of silty clay soil does not approach 55 ksi. On the other hand, if the upper portion of the silty clay soil has a modulus of 55 ksi, the AC thickness estimated by SASW is 7.1 inches, very close to actual AC thickness of 7 inches.

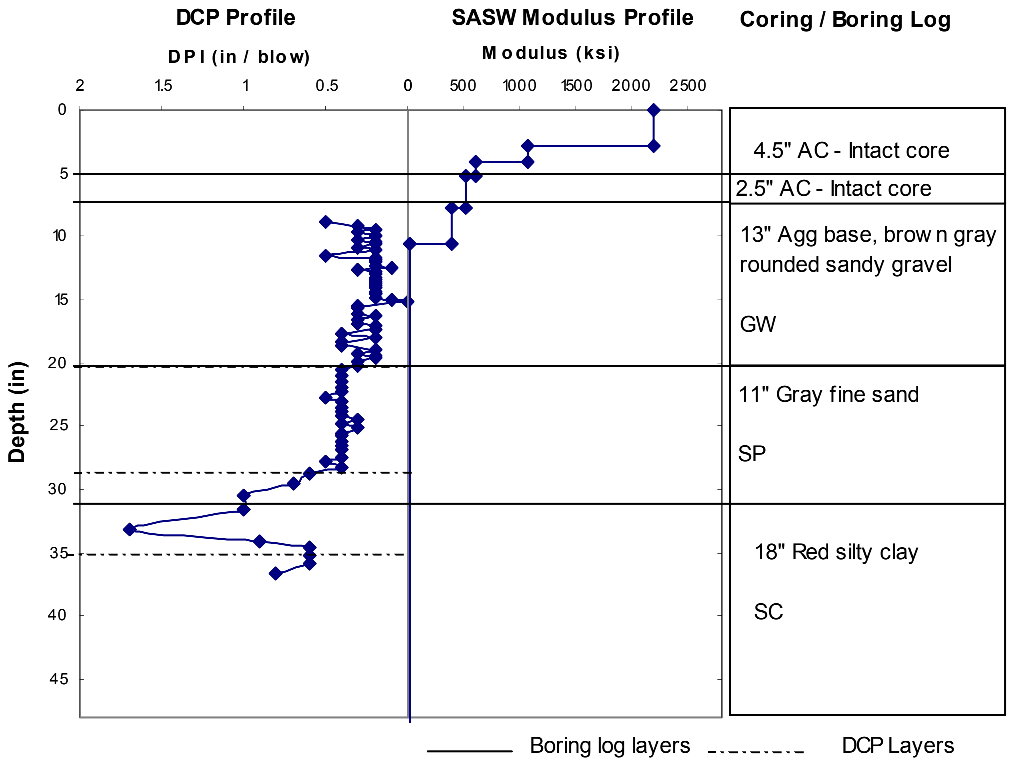

Figure 2: Results of tests carried out at Ada Municipal.

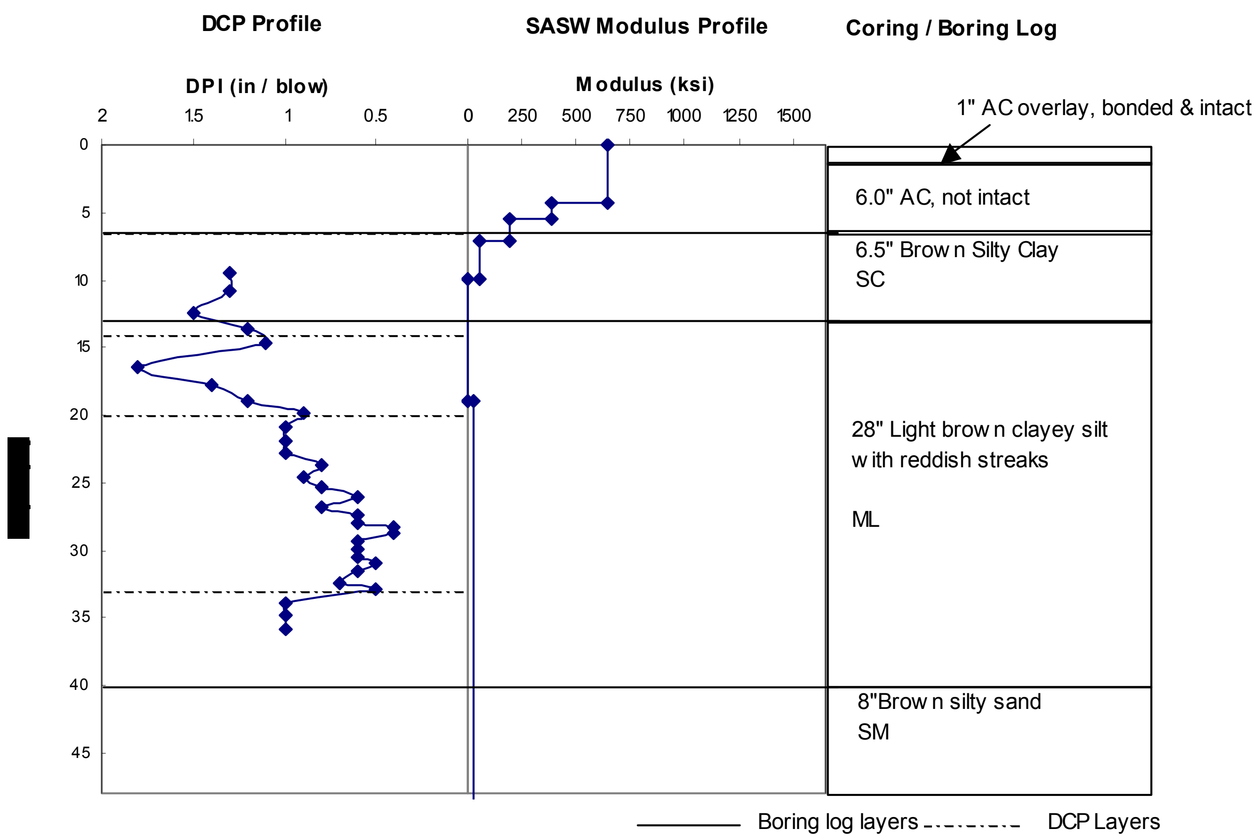

Figure 3. Results of tests carried out at Antler Municipal Airport

Results of SASW testing and analysis at Chandler are presented in Figure 4 along with results of DCP testing and visual classification of pavement core and extracted soil samples. SASW data reveals three constant modulus layers with moduli decreasing from 1500 ksi at the surface to approximately 490

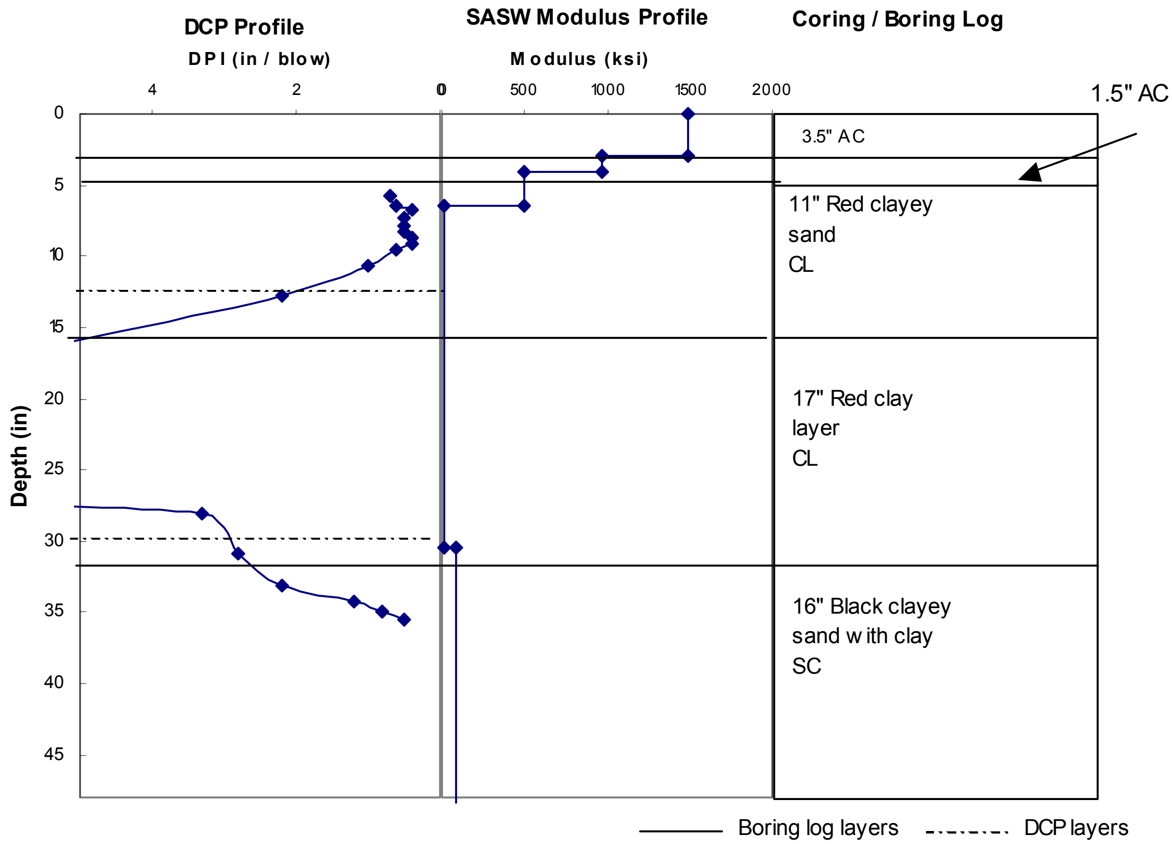

Figure 4: Results of testing at Chandler Airport

ksi at a depth of 6.5 inches. The AC overlay modulus is much greater than that of the original AC layer. The reduction in modulus from 1500 ksi to approximately 950 ksi is consistent with the intersection of the AC overlay and the original AC layer. Without the benefit of a boring log, it is reasonable to assume a SASW-predicted surface course thickness of 6.5 inches. Hence, SASW over predicts the actual total AC thickness of 5.0 inches by 40%. The Chandler data is consistent with the trend observed in Ada and Antlers in that the SASW predicts an artificial stiff layer directly beneath the surface course.

4.2 Rigid pavement surface course

The results of testing at Chickasha and Duncan are presented in Figures 5 and 6, respectively. The results illustrated in Figure 5 exhibit a trend similar to that observed in results of testing on AC pavements. Without the benefit of boring log data, it is difficult to quantify the PCC thickness. One could

The worst case logically predict PCC thickness values of 7.0, 8.0, 10.0 and maybe 17.0 inches. The worst case scenario, i.e., SASW-estimated PCC thickness of 17.0 inches, results in over prediction by almost 150%. The best case scenario, i.e., SASW-estimated PCC thickness of 7.0 inches, is quite accurate. A similar trend persists in Figure 6 as a SASW-estimated modulus of 2000 ksi extends to a depth of 12 inches, overpredicting the PCC thickness by 40%. The SASW data does reveal a significant reduction in PCC modulus at a depth between 1 and 5 inches.

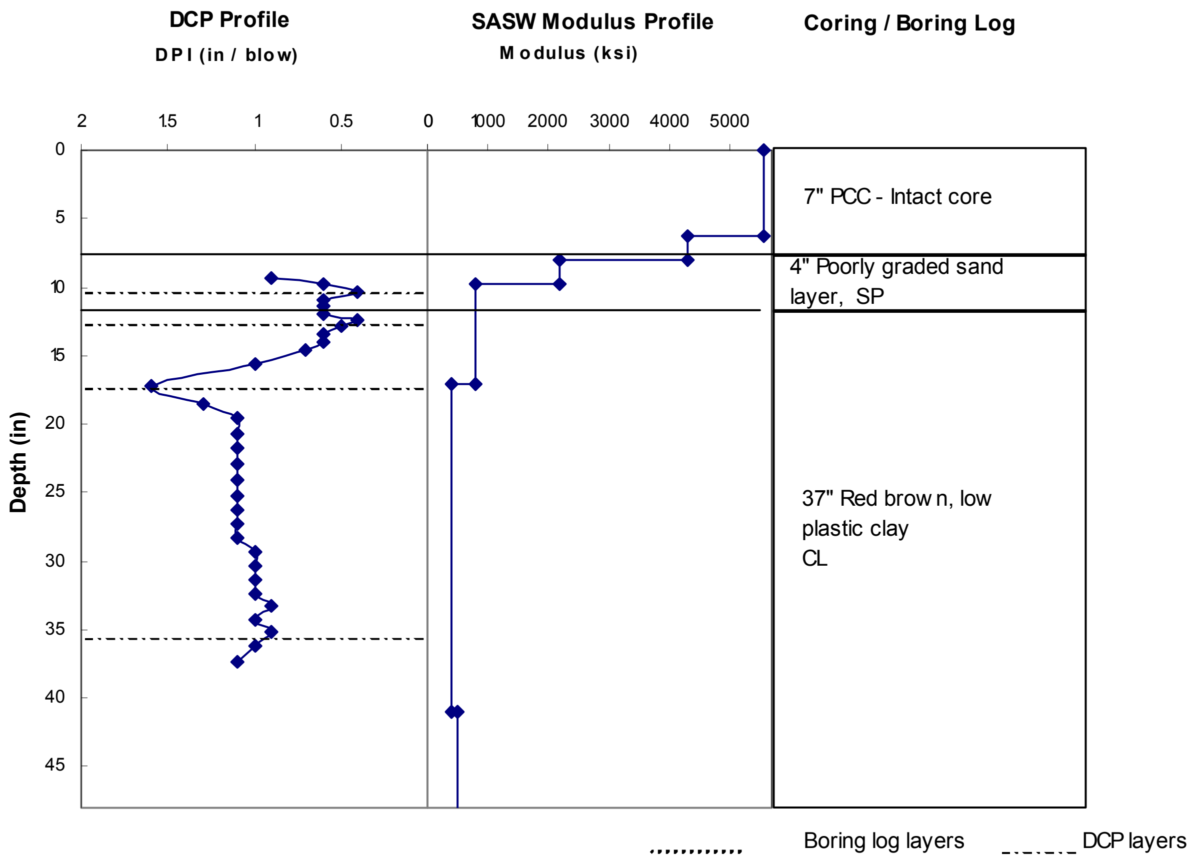

Figure 5: Results of testing at Chickasha Airport

4.3 Base and subbase sections

Table 3 presents a comparison of SASW estimated base and sub-base thickness with boring logs and DCP profiles. At Ada, SASW back-calculated thickness of pavement base and subbase differs by about 17% from boring logs. In Figure 2, it is observed that there was a good correlation between the DCP and the boring log. DCP testing detected a slight increase in DPI at a depth of 20 inches, at the interface between the aggregate base and the subbase. SASW did not detect this layer change nor did it detect a softer region from 27.5 to about 35 inches as observed in the DCP profile in Figure 2.

As observed in Figure 3 and Table 3, layer thickness estimated from boring logs and DCP at Antlers were within 1% of each other, but SASW yielded significantly different results. However, even with this difference, there were some noticeable similarities in the variation of DPI and SASW modulus profiles with depth. Although SASW did not detect the interface between the base and subgrade, it did detect a stiffer zone at a depth of about 19 inches. The DCP results also exhibited a significant drop in DPI at this depth. The DPI profile estimated a softer region from 25 to 34 inches. No such trend was reported by SASW at this depth.

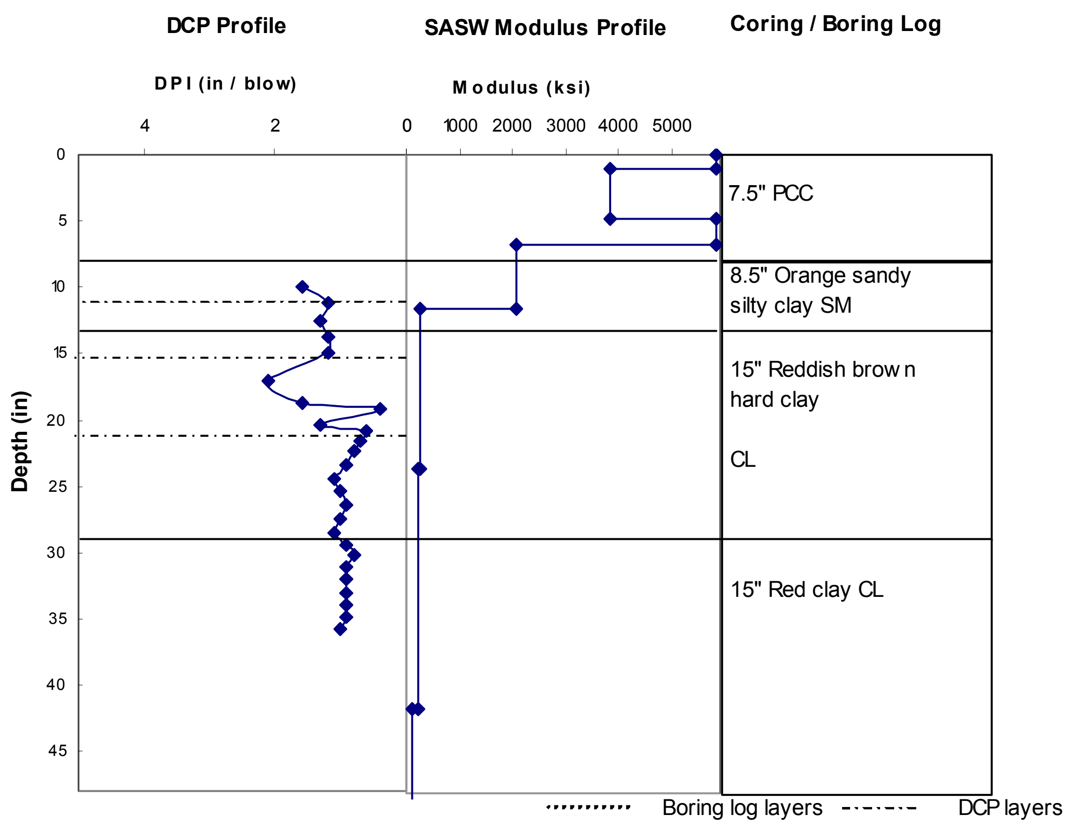

Figure 6: Results from Duncan Airport

In Figure 4, it can be observed that the DPI and SASW modulus profiles correlate at some depths and do not correlate at others. The SASW method was unable to detect the very soft layer beginning at a depth of approximately 10 inches as indicated by the DCP results. The SASW data did corroborate with the DCP data indicating a stiffer layer beginning at a depth of approximately 30 inches. As presented in Table 3, the difference between SASW estimated layer thicknesses and those from boring logs was under 6%. The comparison with DCP testing yielded similar results.

Table 3: Determination of base & subbase thickness

Airport	Total thickness of base & subbase (in)			Difference (%)	
	Coring	DCP	SASW	Coring / SASW	DCP / SASW
Ada	24.0	21.2*	28.0	16.7	32.0
Antlers	6.5	6.6*@	2.1	67.7	68.2
Chandler	28.0	24.1*	26.4	5.7	9.5
Chickasha	4.0	3.3*@	3.6	10.0	9.1
Duncan	23.5	13.9*	16.8	28.5	20.8

***Correcting the effect of disturbance due to core sample removal**
@ base thickness only

As illustrated in Figure 5, the difference between SASW-estimated layer thicknesses and those determined from boring logs and DCP testing at Chickasha is less than 10.0%. SASW modulus variation with depth closely resembled DPI variation with depth. At Duncan, a fair correlation between the DCP and

SASW modulus profile was observed (see Fig. 6). As evidenced in Table 3, the SASW-estimated layer thicknesses differed by 28% with boring logs and by 20.5% with DCP testing.

4.4 Pavement Subgrade

As summarized in Table 4, SASW-estimated subgrade moduli were greater under PCC pavements than those beneath AC pavements. Under AC pavements, the subgrade moduli were observed to fall in a range of 11 - 24 ksi while subgrade moduli beneath PCC pavements were at least 15 times greater, ranging from 230 to 382 ksi. Subgrade DPI values under both AC and PCC pavements were similar, however, with values ranging from 0.5 to 1.0 inches per blow.

Table 4: Estimation of pavement subgrade modulus

Airport	Type of pavement	Subgrade Modulus (ksi)
Ada Municipal	AC	13.0
Antlers Municipal	AC	24.0
Chandler Municipal	AC	11.4
Chickasha	PCC	382
Duncan	PCC	230

5.0 Conclusions

The SASW method provides a valuable tool for the mechanistic characterization of GA airport pavements. However, without the benefit of pavement cores and boring logs, interpretation can lead to significant errors in thickness prediction. In the absence of section details the method significantly over-predicted layer thicknesses by 30-150%. In each pavement case, SASW predicts an artificial layer with high modulus at the top of the base layer. By using the coring and boring information, the SASW predicted modulus profiles allow better interpretation of layer thickness. In most cases, SASW was unable to detect base, subbase and subgrade layer changes. Results of this study suggest the requirement of at least one boring near a test section to better comprehend the results of SASW testing. When compared to the more sensitive DCP soil profiling tool, SASW was able to detect layer changes when DPI varied by more than 1 inches per blow. Subgrade moduli determined using the SASW method are significantly over-predicted in the case of PCC pavements.

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